A New Telemetry System for Measuring Core Body Temperature in Livestock and Poultry

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Abstract. *Core body temperature is an important physiological measure of animal thermoregulatory responses to environmental stimuli. A new telemetric body temperature measurement system was evaluated by three independent laboratories for its research application in poultry, swine, beef, and dairy cattle. In the case of poultry and swine, the system employs surgery–free temperature sensors that are orally administered to allow short–term monitoring. Computational algorithms were developed and used to filter out spurious data. The results indicate that successful employment of the body–temperature measurement method – telemetric or other measurement systems such as rectal or tympanic method, will depend on the specific application. However, due to the cost of the system, the surgeries involved (in some applications), and the need for filtering of data, careful consideration needs to be given to ensure that telemetry is the ideal method for the experiment protocol.*

Keywords. *Beef cattle, Dairy cattle, Poultry, Swine, Body temperature, Telemetry system.*

Body temperature is an important parameter for assessing animal stress. The most common method of body temperature measurement has been discrete sampling with a mercury rectal thermometer, and more recently with electronic data loggers. Continuous measurements are commonly taken either rectally or near the tympanic membrane. Rectal probes are easy to insert and are generally non–invasive, but they can only be inserted for a short period of time (approximately five days in cattle) without causing tissue irritation. In poultry, an additional disadvantage to rectal probes is that bird movement is restricted, and the probe tends to fall out. Tympanic probes can be used in both swine and cattle, with and without anesthesia, respectively (Brown–Brandl et al., 1999; Paul et al., 1999). The tympanic probes need to be alternated between ears every 7 to 10 days in cattle to reduce the potential for ear infections. In pigs, both probes are inserted at the same time and can remain functional in the ear for three to five weeks. With these constraints, an improved method of measuring body temperature continuously for an extended time is desirable.

Telemetry systems have been used in wildlife, livestock, and medical research for approximately 40 years. They have been used to measure a variety of physiological parameters including body temperature, blood pressure, movement, behavior, fluid flow, pH, heart rate, respiration rate, and brain activity (Bligh and Heal, 1974; Data Sciences, Intl., 2000). Early telemetry systems had several disadvantages, including a short transmitter battery life and long–term drift in the temperature sensors (e.g., 0.2°C in one month; Riley, 1970). Some temperature sensors had the transmitter outside the body and a wire running into the animal's body to measure temperature (Bligh and Heal, 1974; Dorminey and Howes, 1969).

Currently, commercially available telemetry systems can be divided into two types, one commonly used in the wildlife industry, and the other used in medical research. The systems used in the wildlife industry monitor animals over long distances and are designed mainly for animal tracking; however, temperature sensors and heart rate monitors are also available. Temperature sensors have an accuracy of 0.1°C, but have some known drift associated with their use and have a non–linear response within the calibration range (Telonics, 2000a; AVM Instrument Co., Ltd., 2000). This type of system has been successfully used for livestock and poultry research (Hetzel et al., 1988; Hamrita et al., 1997; Lacey et al., 2000a, 2000b). However, there are complications in using this system in small rooms, depending on the room configuration and construction. Additional antennae may be needed, and there is a potential for bad readings due to ricocheting signals in small rooms (Telonics, 2000b).

The biomedical telemetry systems are designed to be used in laboratory environments, therefore have a weaker signal strength, traveling less than 2 m, and are very expensive, making them unsuitable (in their current form) for livestock

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research. Some biomedical sensors do not have the signal strength to penetrate the muscle layers and the hide of a large animal (e.g., cattle). However, biomedical systems have a more extensive list of sensors available, and the temperature sensors have very good stability and linear response.

Neither type of telemetry system was designed, nor is ideal, for all situations in monitoring physiological parameters in livestock/poultry research. There are very few companies producing telemetry equipment, and even fewer companies currently marketing to the livestock researchers/industry. However, telemetry systems are continuing to improve, making them a viable alternative that needs to be reevaluated.

OBJECTIVE

The objective of this article was to describe the comparative performance of a new telemetry system for core–body temperature measurements in poultry, beef cattle, swine, and dairy cattle.

MATERIALS AND METHODS

The telemetry system (HQ, Inc., West Palmetto, Fla.) was used in the studies based on the specified resolution of temperature transmitters, overall accuracy of the system, and flexibility of taking measurements on both free roaming and housed animals. Transmitters were specified based on battery life and size of transmitters, and transmitting distance.

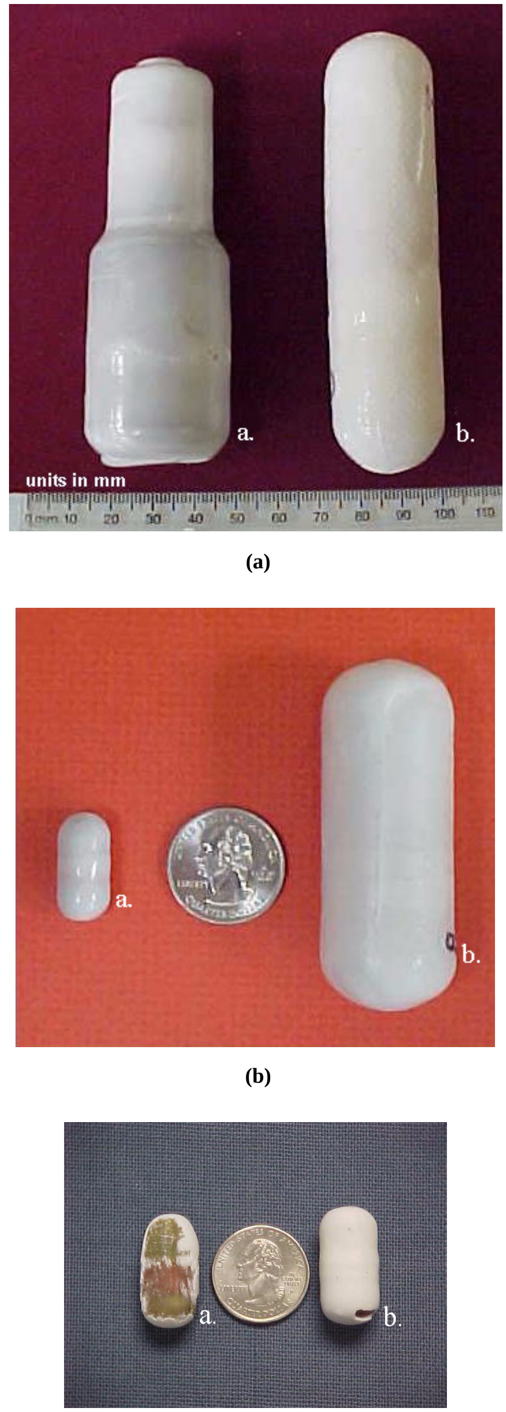
DATA LOGGING SYSTEMS

Miniaturized ambulatory receiver/loggers were used in the trials with feedlot steers, swine, and dairy cattle. These loggers are small (12 × 6 × 2.5 cm), lightweight (< 200 g), powered by a 9–VDC battery, and record data from only one transmitter at a time. The loggers draw 5–mA current in standby mode and 20 mA in reading mode; therefore, battery life depends on sampling frequency. At 1–min sampling intervals, a lithium battery will last approximately 10 days. The transmitter transmits only a short distance (maximum of 0.5 m from the animal), and the logger needs to be setup for each individual transmitter. Therefore, each animal is required to either be in close proximity to the logger (for example in a tie stall or a small pen) or have the logger physically secured on the animal (e.g. in a pouch on a harness or a vest). This logger has a data storage capacity of 25,000 readings.

An eight–channel telemetric system (four channels at 262 kHz and four channels at 300 kHz) was used for the poultry studies. The system can be directly interfaced with a computer via a RS–232 port. The receiver dimensions are 30.5 cm (W) × 25.4 cm (H) × 12.7 cm (D), and it has a LCD panel and a keypad for entering calibration and setup information about transmitters being used. This system can log up to 10,000 data points independent of the computer, or automatically download data into spreadsheet files. The accompanying software also generates real–time display of the measured temperature readings on the PC monitor.

TRANSMITTERS

These transmitters (fig. 1) are considered single–time use because the batteries cannot be replaced; however, at approximately 1/6 to1/3 of the cost of the wildlife–type transmitters, they were considered practical. The useful life of the transmitters varied with the size of the transmitter, which dictated battery size.



(a)

(b)

(c)

Figure 1. (a) Cattle transmitters: a. improved transmitter, b. original transmitter; (b) Pig transmitters: a. ingestible transmitter, b. implantable transmitter; (c) Poultry transmitters: a. transmitter after several uses, b. new poultry transmitter.

Cattle

The transmitters selected for the cattle studies were cylindrically shaped, approximately 10 cm long and 3 cm in diameter (fig. 1a). The maximum signal transmission distance was about 2 m through air, depending on the orientation of the sensors. Battery life of the transmitter was approximately six months.

A licensed veterinarian implanted the transmitters in the omental sling (located in the abdominal cavity) using the following procedure. The transmitters were stored in zepharin chloride for a minimum of 2 h prior to implantation to provide cold sterilization, without jeopardizing the transmitters themselves. The animal was restrained in a squeeze chute. The hair on the flank was clipped and the skin was surgically scrubbed with betadine and alcohol preparation. The steers were given a line block with 60 cc of 2% lidocaine hydrochloride. A celiotomy was performed with a 20–cm vertical incision in the left flank skin and musculature to insert a temperature transmitter. The muscle layers were closed with #3 chromic catgut and the skin was closed with #4 vetafil. Skin sutures were removed after 14 days. Transmitters were retrieved (when necessary) using the same procedure used to install them, or they were retrieved at slaughter. In the case of dairy cattle, a second installation procedure involved placement of the transmitter in the rumen of a fistulated cow.

Swine

Two types of transmitters were used in the swine studies (fig. 1b): an implantable transmitter (6 cm long × 2.5 cm dia.; approximately 1.25–m transmit distance) and an ingestible transmitter (2.5 cm long × 1 cm dia.; approximately 0.5–m transmit distance). The ingestible transmitter was administered using a balling gun to place the transmitter in the back of the pig's mouth. While the transmitter was being placed, the pig was held in a small transfer cart, with head restrained and mouth kept open using a loop in a nylon rope around its snout. It was found that the nylon rope was more humane and caused significantly less stress on the animal than a snare. To ensure the pig swallowed the transmitter, a small amount of water was administered into the pig's mouth.

A surgical procedure was developed to implant sensors in the abdominal cavity. The transmitters were stored in zepharin chloride for a minimum of 2 h prior to implantation to provide cold sterilization. The animal was anesthetized using penathol and maintained using halothane. The hair on the flank was clipped and the skin was surgically scrubbed with betadine and alcohol preparation. A celiotomy was performed with a 10–cm vertical incision in the left flank skin and musculature to insert a temperature transmitter. The peritoneal membranes were closed with #0 chromic catgut, muscle layers were closed with #2 chromic catgut, and the skin was closed with #3 chromic catgut. Transmitters were retrieved at slaughter.

Poultry

The transmitters used in the poultry studies were also cylindrically shaped, measuring 2.5 to 2.8 cm long and 1.2 to 1.5 cm in diameter (fig. 1c). Their transmitting distance was strongly a function of antennae design, typically varying from 200 to 750 cm. The ingestible transmitters were first dipped in vegetable oil, and then placed in the bird's mouth past its tongue so the bird would swallow it. Typically, it took 4 to 6 h for the transmitter to naturally move from the crop to the gizzard. If the transmitter remained in the crop, as determined by visual inspection and feel, the bird was not used. Subsequently it was found that gentle stroke of the crop greatly facilitated passage of the transmitter to the gizzard (Tao and Xin, 2003). After each trial, the bird was sacrificed and the transmitter was retrieved and reused if its battery life and physical condition permitted.

Data Handling

Data collected with the portable units (cattle and pigs) were downloaded using software provided with the system. The downloaded data was converted to ASCII text data into a time–stamped comma delimited file, for import into any spreadsheet or other analysis software. The data for the poultry studies were transmitted from the receiver to the host PC using Hyper Terminal link. Collected data were evaluated for stability and the need for further processing.

System Evaluation

The systems were thoroughly tested both before and after the transmitters were placed in the animals by three independent labs: USDA–ARS USMARC in Clay Center, Nebraska — feedlot cattle and swine systems; Iowa State University in Ames, Iowa — poultry system; and University of Florida, Gainesville, Florida — dairy cattle system.

Transmitters were factory calibrated using a stable–temperature water bath, a NIST–certified resistive temperature detector (RTD), and a frequency counter (Hicks et al., 2001). Each transmitter was supplied with a unique serial number and calibration code, consisting of the slope and offset. The serial number and the calibration code were entered into the receiver. A calibration check was performed on the transmitters prior to their use.

Although transmitters were pre–calibrated by the company, a calibration check on transmitters used with the feedlot steers was performed. Each of the transmitter's calibration was checked using a digital refrigerated/heated circulating water bath (0.01°C) prior to implantation, using the procedure described below. Two separate shipments of nine cattle transmitters were checked independently on shipments received in May and October, 2000. The calibration of all transmitters was verified between the temperatures of 35°C and 45°C, allowing 20 min at each temperature for the sensor to stabilize. The first transmitter to undergo this procedure was checked for hysteresis and response time. The hysteresis was tested by exposing the transmitter to temperatures ranging from 35°C to 45°C. Time constants, defined as the time (min) to reach approximately 63.2% ($1-1/e$) of the total temperature increase, were calculated based on a step increase for both the new cattle transmitter and the ingestible swine sensor. The response time was checked on one sensor in each of two shipments by using a terminated ramp function between 40°C and 41°C. The transmitters were allowed 20 min to stabilize in the water bath before the test began.

A calibration correction was developed for each individual transmitter (PROC REG, SAS, 2000). T–tests were performed to assess whether the slope of each regression line was significantly different from unity, and the intercept of each regression line was significantly different from zero. Differences in the two shipments of sensors were tested using the regression coefficients, generated using the regression procedure, and the general linear model procedure in SAS (SAS, 2000).

To verify that all hand–held loggers were recording the same temperature from a given frequency, two homogeneity tests were conducted on the hand–held loggers. All loggers were configured to record temperatures from a single transmitter with sampling interval of 1 min. Test 1 was conducted for a 24–h period; the loggers were set in two rows facing a single implant approximately 10 cm apart. Test 2 was conducted for a 90–h period; loggers were set in a circle with the approximate diameter of 30 cm facing a single transmitter in the center of the circle.

After the transmitters were installed, concurrent measurements of rectal temperatures were conducted and compared with telemetric temperature readings on feedlot cattle, dairy cattle, and poultry. Due to experimental protocol, rectal temperatures could not be obtained from the pigs. Rectal temperatures were selected as a standard measurement because of its common use across all species and its general acceptance as an indication of core temperature (Hahn et al., 1990; Hetzel et al., 1988).

Beef Cattle

Seven animals were used in four, three–day tests. The four periods had air temperatures of 18±7°C, 18°C constant, 32±7°C, and 32°C constant. These conditions were applied to all animals in the same order, and were applied at least 24 h prior to the initiation of the measurements. Rectal temperatures were measured using a 30–Ohm thermistor (YSI Incorporated, Yellow Springs, Ohio) and were electronically logged using a Pace Scientific data logger on a 1–min basis (±0.1°C). Telemetry data were also logged on a 1–min basis. Data were compared using general linear model procedures (SAS, 2000). A paired t–test (Dowdy and Wearden, 1985) was used to compare animal by treatment means to determine if overall differences were statistically significant.

Dairy Cattle

Three dairy cows were used over a five–day comparison test. Daily measurements of rectal (using a mercury thermometer, ±0.1°C) and telemetry temperatures were taken simultaneously for five days. Statistical analysis was performed using a paired t–test.

Poultry

Seven tests were conducted measuring body temperatures with both rectal and the telemetry system. Each test consisted of five, 10–point consecutive samples collected at 10–s intervals. The rectal temperature was recorded using a Pace pocket logger and a 30–k Ohm thermistor (model PT907, Pace Scientific Inc., Charlotte, N.C.) (±0.1°C). Six of the tests had 28.5–min intervals between samples, while the seventh test used 18.5 min between session intervals. Three tests were conducted at ambient conditions of 37.8°C, 41% RH; two tests at 32.2°C, 52% RH; one at 32.2°C, 41% RH; and one test at 26.7°C and 59% RH. All tests had an air velocity of 0.2 m/s. One laying hen was used per test. Each bird was housed in an individual wire cage during the test, and the antenna was approximately 0.2 m away from the sensor. Mean rectal and core body temperatures for the seven tests were compared using a paired t–test.

Results and Discussion

Calibration of Transmitters

All sensors had a linear response and hysteresis was small and not measurable. The sensor transfer functions were very similarly represented by an average slope comparison of 1.00 ± 0.01, which was not significantly different from 1 ($P = 0.588$). The individual slopes ranged from 0.979 to 1.019, and four out of 18 transmitters had slopes significantly different from one. The offset error or average intercept was –0.27°C ± 0.51°C, which was significantly different from 0 ($P = 0.0388$). The individual intercepts ranged from –0.975 to 1.034, and 3 out of 18 transmitters had intercepts that were significantly different from 0.

Transmitters used in the poultry studies were checked at one temperature inside a wind tunnel in an environmentally controlled room using a NIST–certified mercury thermometer as the standard reference. The offset of these transmitters ranged from –0.2°C to 0.1°C, averaging 0.01°C.

The original cattle transmitters had a volume of approximately 52 cm^3, and the temperature sensor was embedded in the epoxy approximately 2 cm from the end. The second set of cattle transmitters ordered for use at MARC had a larger battery, and thus a larger volume of approximately 61 cm^3 (fig. 1A). However, the temperature sensor was embedded in the epoxy at the end of the transmitter, thus allowing for a faster response time. The response time of the new cattle transmitters was improved (shorter time delay) by more than 35% from the original transmitter (fig. 2). The time constant of the new cattle sensor, as determined by a step increase in temperature, was found to be 274.8 ± 23.5 s. In comparison, the smallest transmitter used in these experiments, ingestible swine transmitter, with a volume of 1.75 cm^3 had a time constant of 38.8 ± 3.3 s.

Logger Performance

Small differences were found when the hand–held loggers were compared against one another. As depicted in figure 3, these 10 loggers tracked the same transmitter with a standard error of 0.01°C, the maximum error was ±0.05. These offsets were consistent between tests. According to the company (HQ, 2001), these offsets are due to calibration of the logger (completed at the factory).

Data Filtering

The time–series data collected exhibited random noise (fig. 6). A clear pattern of core body temperature is obvious; however, a number of points can be identified as spurious.

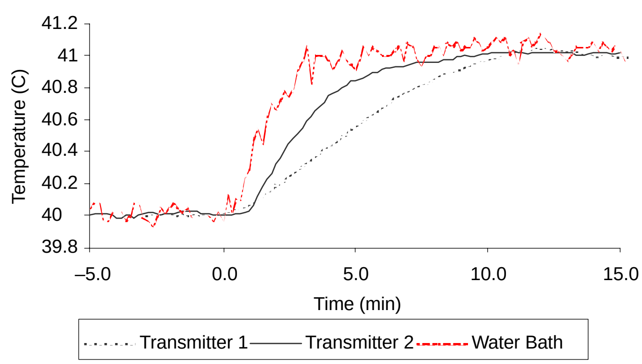


Figure 2. Responses of the two types of the cattle transmitters and the water bath to a ramped change in temperature.

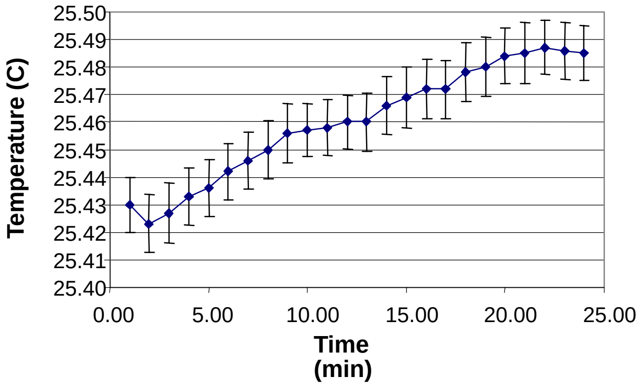


Figure 3. Ambient temperature (average and standard error) simultaneously recorded on ten loggers programmed to read a single transmitter at a distance of 30 cm.

Two different filters were developed for conditioning the time–series data. One filter simply removes the skeptical points using a series of running average filters (filter 1). The other replaces the skeptical points with an estimate (filter 2), and uses a series of running averages to smooth the curve. The two different filters are necessary because ideally only actual data points should be used in the statistical analysis; however, in some analysis (i.e. repeated measures) there can be no missing data. Details of the two filtering methods are presented in two flow charts (figs. 4 and 5).

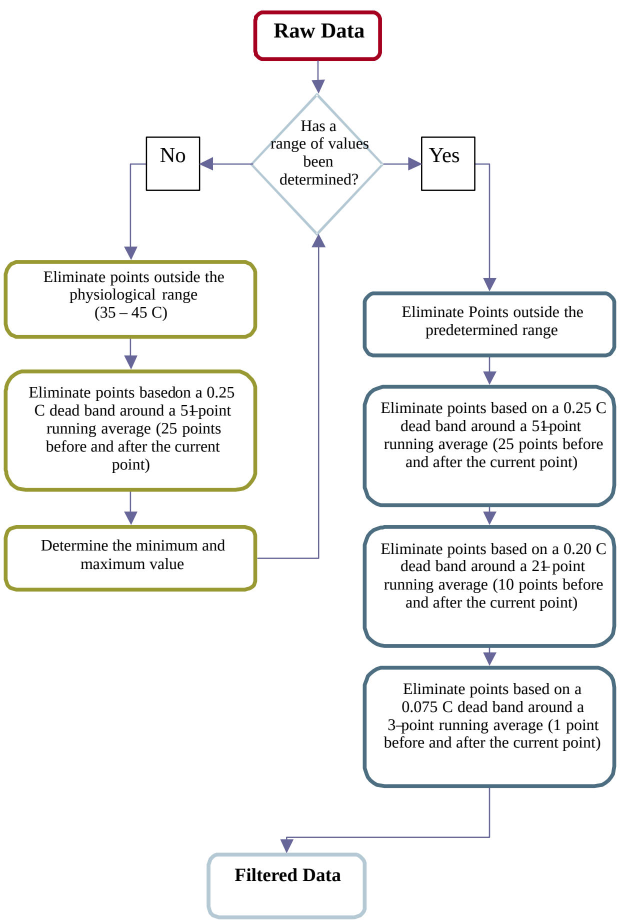


Figure 4. Flow chart describing filter 1, which removes bad points.

Correlation Between Methods of Measuring Body Temperature

Cattle

Table 1 shows the average core–body and rectal temperatures for both heat stress and thermoneutral ambient conditions, for beef and dairy cattle. Significant differences were detected between rectal temperature and telemetry temperature in both the beef and the dairy cattle. The beef cattle results showed a higher rectal temperature (0.4°C), while the results from the dairy cattle showed a higher telemetry temperature (0.4°C). With the large range of differences found in both experiments, it is difficult to determine a species effect.

Poultry

There were no significant differences noted between rectal and core body temperatures in laying hens. Table 1 shows the average core–body and rectal temperatures for both heat stress and thermoneutral conditions.

Discussion

Beef Cattle

During the MARC beef experiment, several loggers stopped recording data and were returned to the manufacturer for repair. The problem was identified as a torsion stress caused by the tight–fitting pouches on the harness, which held the loggers. This problem was resolved by placing the logger inside a soft neoprene pouch, and then inside a hard plastic case with a lid, which prevented twisting of the logger itself by allowing the plastic case to prevent or absorb the stress without transferring it to the logger. Since this protocol was implemented, no additional problems have occurred.

Although great care was taken when surgically implanting the sensors to ensure proper placement, at slaughter most sensors were found outside the omental sling. It was hypothesized that the gut motility moved the sensors up and out of the omental sling, which is possible because the omental sling is not completely enclosed, but has an opening on the dorsal side of the rumen. Once outside the omental sling, the implant came to rest ventrally in the abdominal cavity. Consequently, the surgery protocol was modified by making a smaller incision (8 to 10 cm vs. 15+ cm long) and placing the transmitter inside the peritoneal cavity, not in the omental sling. Eleven months after the original implantation surgery, cattle were slaughtered. At slaughter, the tissue surrounding the implant was evaluated. It appeared that the implants caused very little or no tissue reaction.

Laying Hens

Several different antenna designs were evaluated including loop, block, plate–type, and omni–directional “L”–shaped antennae. The loop and block antennae did not receive a good signal, so they were eliminated. The plate antenna received an improved signal but was subject to large influence of bird movement. By comparison, the “L”–shaped antenna provided the best signal reception, even within the cages that served to attenuate the signal.

The transmitters typically survived five to seven days of use; although the batteries were good for approximately 15 days, the harsh environment of the gizzard usually

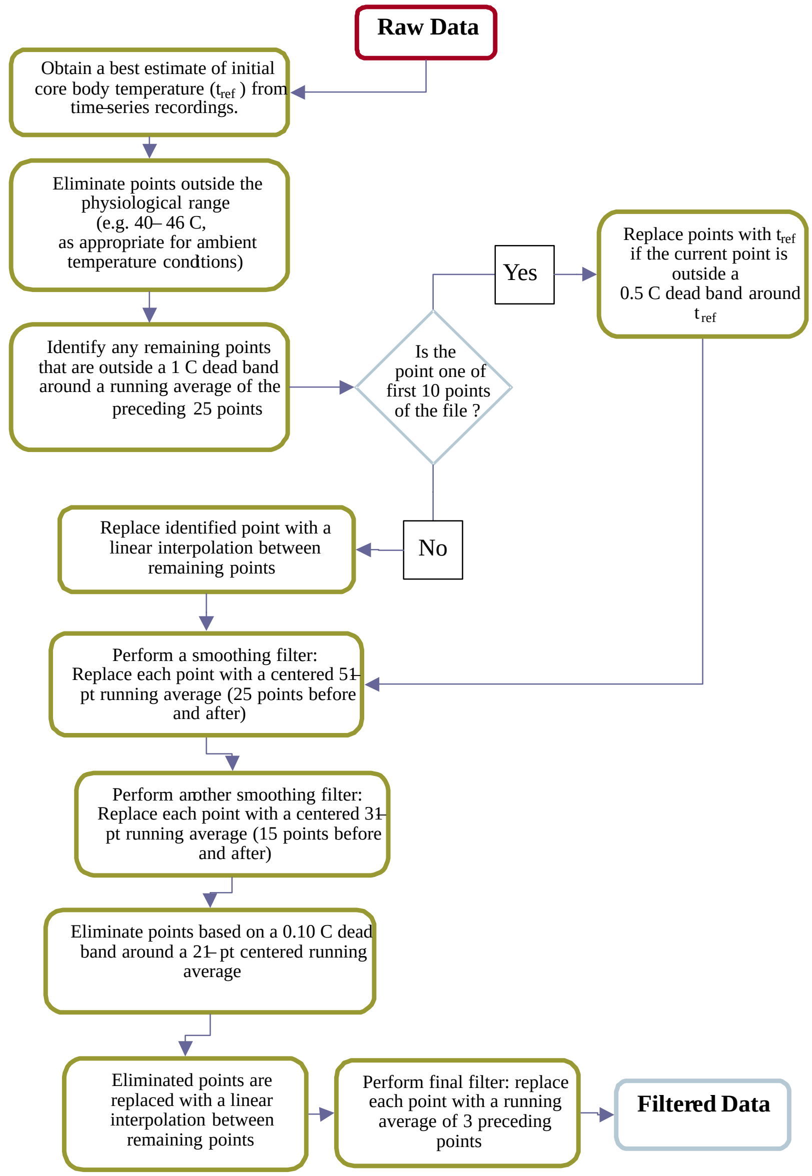


Figure 5. Flow chart describing filter 2, which replaces bad points to eliminate missing data.

compromised the electronic connections. Figure 1c shows the poultry transmitters after multiple cycles of use. Transmitters in the figure had some of the silicone coating removed.

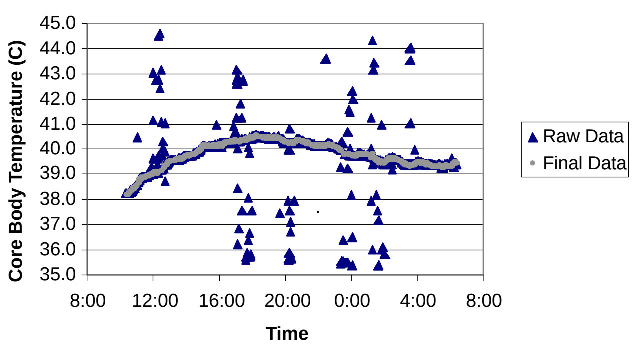


Figure 6. A representative sample of filtered and unfiltered data collected over one day collected on a beef steer in an environmental chamber.

CONCLUSIONS

A telemetry system was evaluated by three independent laboratories for use in beef cattle, pigs, dairy cows, and poultry. Overall, telemetry was found to be a viable alternative to other methods of monitoring body temperature in a research setting. However, due to the cost of the system, the surgeries involved (in some applications), and the need for filtering of data, careful consideration needs to be given to ensure that telemetry is the best method for the experimental protocol. Where surgery is involved, other methods of body temperature should be considered first. For short–term measurements in cattle, less than five days and a minimum of one week between measurement periods, the rectal probe would be the ideal method. For applications in cattle where the need is for longer term, 7 to 10 days with only a few replications, a tympanic probe should be considered. For short–term measurements in swine, less than 48 h, the best method would be the ingestible telemetry; however, for longer–term measurements, either the tympanic probe or the implantable telemetry transmitter could be used. For short–

Table 1. Treatment average body temperature (°C) of three species subjected to thermoneutral (TN) conditions and heat stress conditions (HS) taken using a telemetry system and a rectal probe two methods.

Species and Ambient Conditions	N	Telemetry Temp. (°C)	Rectal Temp. (°C)	Difference[a]			P–Value[b]
				Min	Max	Mean (SE)	
Beef Cattle							
TN[c]	12	38.3	38.7	–0.9	0.5	–0.4±0.2	<0.025
HS[d]	10	39.0	39.4	–1.0	0.5	–0.5±0.2	<0.010
Combined	22	38.6	39.0	–1.0	0.5	–0.4±0.1	<0.005
Dairy Cattle							
TN	5	38.5	38.1	–0.1	1.0	0.4±0.2	NS (P > 0.05)
HS	11	38.8	38.4	–0.3	1.0	0.4±0.1	<0.005
Combined	16	38.7	38.3	–0.3	1.0	0.4±0.1	<0.005
Laying Hens							
TN	1	41.0	41.1	—	—	–0.1	—
HS	6	41.7	41.6	0.0	0.2	0.1±0.03	<0.025
Combined	7	41.6	41.5	–0.1	0.2	0.1±0.04	NS (P > 0.05)

[a] Differences were statistically compared using a paired t–test.
[b] H_o: mean difference is zero; H_A: mean difference not zero.
[c] Thermoneutral conditions were $T_{db} < 24$°C for cattle and $T_{db} = 26$°C for laying hens.
[d] Heat stress conditions were $T_{db} > 27$°C for cattle and $T_{db} > 32$°C for laying hens.

term measurements in poultry, a few hours, the ingestible telemetry transmitter seems to be the best method, providing consistent data with no cabling attached. Perhaps an implantable transmitter would need to be investigated for long–term measurements in poultry. Lastly, telemetry systems continue to make improvements so the systems need to be thoroughly tested on a regular basis.

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